feet of gas at a pressure of 1,800 pounds per square inch. For obtaining the lifting power of the pilot balloon, an ordinary balance or scale pan with a set of metric weights is used at permanent stations for accurate work; for a portable field outfit a bronze chain is used with auxiliary weights. The chain is tied to the balloon and from the number of links supported the lifting power is obtained. For single-theodolite work a standard plotting board is employed, the idea of which was originally due to Sergt. 1st cl., E. R. Ryder, Signal Corps. It consists of a transparent celluloid protractor, whose surface is roughened in order to take a pencil mark, which revolves about a pivot in a board covered with cross-section paper. The board is illustrated in figure 4. The method of operation is as follows: By rotating the celluloid protractor, set the azimuth angle for the given reading on the scaled reference line O M; set the arm O R at the elevation angle read on the quadrant protractor on the cross-section paper; find the intersection of the altitude cross-section line (as read on the altitude reference line O N) with the arm O R and follow along the perpendicular cross-section line to the reference line O M and mark the point. This point is the horizontal projection of the location of the balloon for the given reading and the horizontal distance from start may be read from the scaled reference line if desired. This process is repeated for each reading and results in a series of points which determine the horizontal projection of the balloon's path. To obtain the mean wind direction between any two points, set the two points in question so that they lie along the cross-section lines parallel to the reference O M; the direction from which the wind blows is read at P in the units desired. The wind speed may most conveniently be measured by means of a special scale which reads the velocity directly in the units desired. The standard type of two-theodolite boards is an adapted form of this single board and possesses all its advantages. (See figure and discussion, by W. C. Haines and R. A. Wells, below.) Ballistic wind plotting may also be done on the same board at the same time in any convenient portion not in use for plotting the balloon's course.

Meteorological observations on surface conditions are taken at 8 a. m. and 8 p. m., 75th meridian time, and at 12 noon, local time, and whenever balloon ascensions are made. Standard Weather Bureau practice is followed in the procedure. Cloudiness observations are made every two hours from 6 a. m. to 10 p. m. Regular balloon observations are made at 8 a. m. and 4 p. m., 75th meridian time, and whenever locally desired. When continuous reports on the wind aloft are required observations are made every three or four hours. Observations of other character are made whenever desired by departments of the local posts.

All of the meteorological work of the Army has been done in the closest cooperation with the U. S. Weather Bureau. The Weather Bureau furnished all the instrumental equipment used by the Military Meteorological Service during the first few months, and the resources of the Weather Bureau and the counsel of the Chief of the Weather Bureau and his staff have always been available to the Meteorological Section of the Signal Corps and these have been used freely. Without this assistance from the Weather Bureau the early accomplishments of the Military Meteorological Service in the United States would have been of little consequence.

The Meteorological Section of the Signal Corps was under the general supervision of Lieut. Col. R. A. Millikan from the beginning of its organization, during the war, and to December 31, 1918, and under the general supervision of Lieut. Col. John C. Moore since that date.

Much credit is due the enlisted personnel for the work accomplished. Many of these men left responsible positions to become privates in the Meteorological Service. These men not only performed faithfully the work laid out for them to do, but developed new methods and devices for doing the work. It is impracticable to mention individuals by name, because of the large number of men in the service who have accomplished work that would make them worthy of commendation. The personnel was made up mostly of graduate engineers, physicists, mathematicians, and employees of the Weather Bureau.

It should be noted that no mention is made here of the meteorological work done at the actual battle front in France. The Meteorological Section of the Signal Corps had, however, about 15 officers and approximately 300 enlisted men all trained in meteorology and aerology at the front, and it is thought best that the description of the accomplishments of this portion of the Meteorological Section be left to those who have been engaged in the work overseas.[11]

TWO-THEODOLITE PLOTTING BOARD.

By W. C. Haines and R. A. Wells.

[Dated: Weather Bureau, Washington, D. C., May, 1919.]

This board (fig. 1) is identical with the one-theodolite board that is now being used in the Weather Bureau (essentially, that shown in fig. 4 opp. page 222), with the additional features of (1) a protractor, centered at B, and (2) an elevation scale, CD, both drawn on the cross-section paper base, and (3) a brass arm attached at the center of the celluloid protractor, A. The celluloid protractor is superimposed on the cross-section paper base, so that its index point, or center, A, is at a distance from the index point, B, of the protractor drawn on the cross-section paper, corresponding to the distances between the two observing stations, or the length of the base line.

The data are plotted in the following manner: The celluloid protractor is held securely with its zero on the south. The brass arm is set at the first minute's azimuth reading indicated by the theodolite at A station. A pencil mark is made on the celluloid protractor at the point where the azimuth reading indicated by the theodolite at B station intersects the brass arm, as determined by the lines of the protractor on the base paper. Each successive minute is plotted in the same manner and the points are numbered 1, 2, 3, etc.

As an example, let us take the data as to elevation angle and azimuths given in Table 1, and find the other data indicated in the table.

Table 1.

Station A.—Zero=north.							Station B.—Zero=north.	
Minutes.	Elevation angle.	Azimuth angle.	Distance from A.	Altitude.	Wind direction in degrees.	Wind velocity in meters per second.	Minutes.	Azimuth angle.
1	20.0	310.0	550	200	315	10.5	1	190.0 [315°=S. E.
2	18.1	315.0	1,255	410	324	10.7	2	205.0 324°=S. E.
3	18.5	320.0	1,820	610	336	10.2	3	220.0 336°=S. S. E.]
4	18.5	325.0	2,425	810	....	....	4	240.0.

[11] Now in preparation for a later issue of the Review.—Ed.

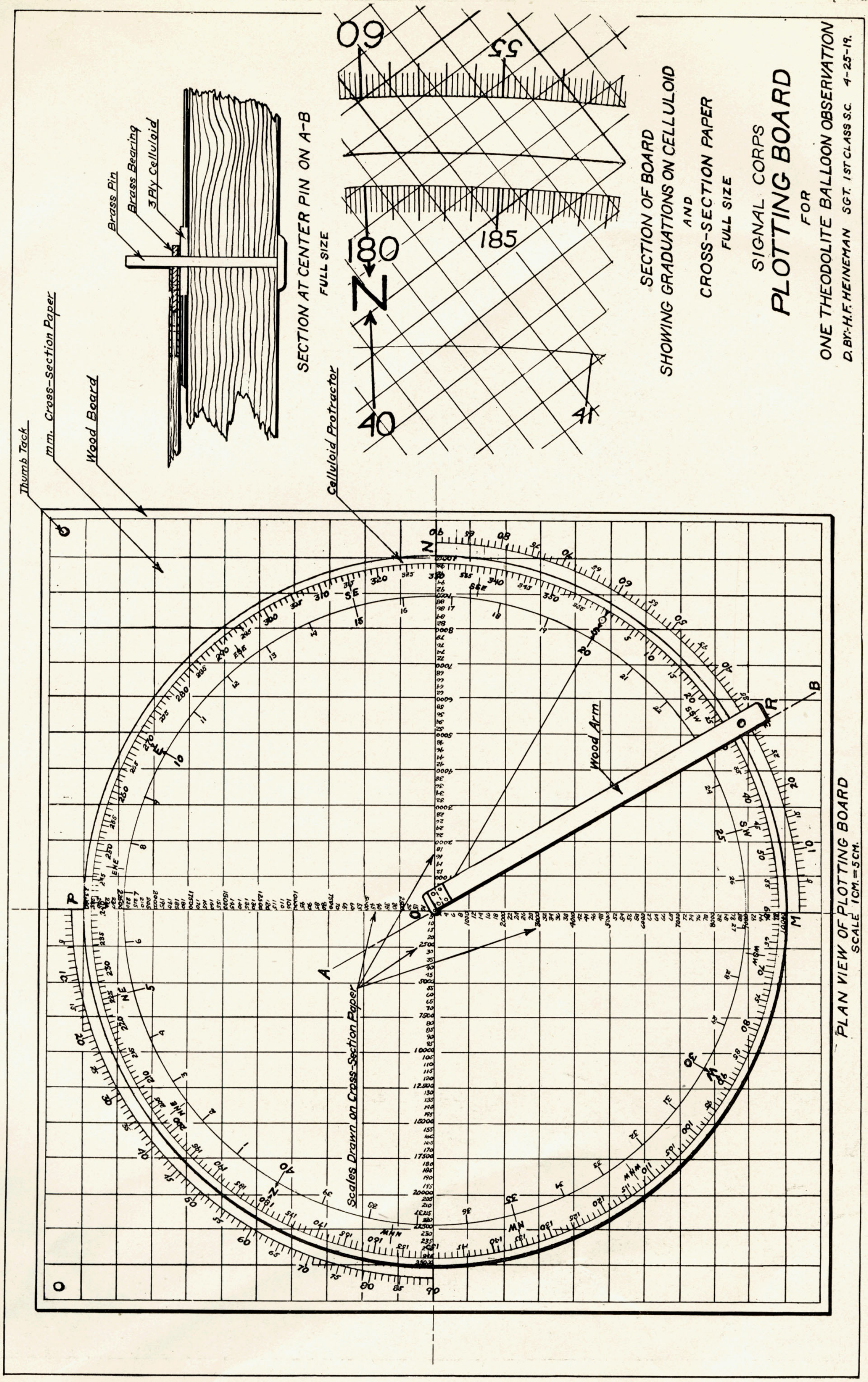

FIG. 4.—Essentials of the Signal Corps single-theodolite plotting board.

[To face p. 223.]

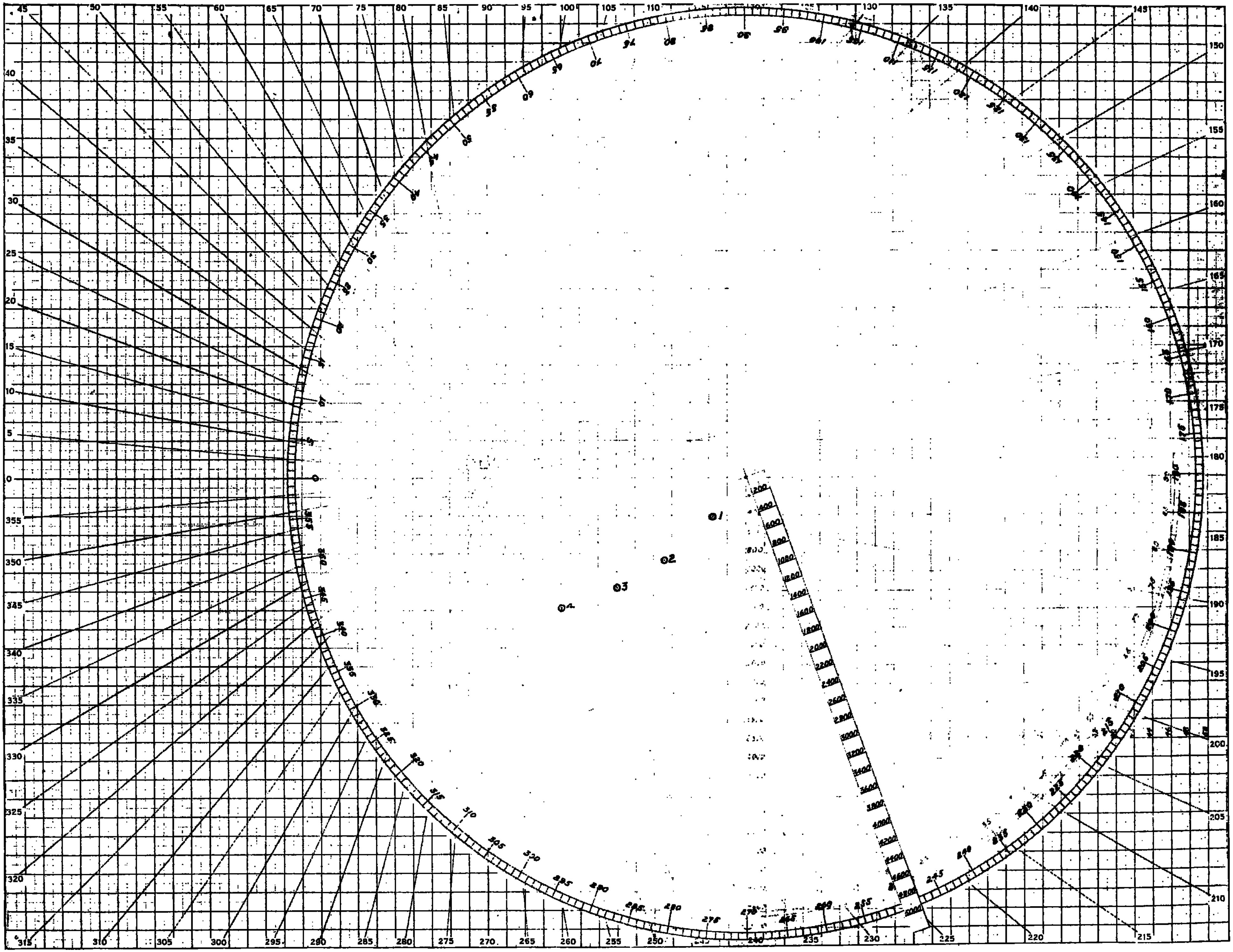

FIG. 1.—Two-theodolite plotting board.

The distance between stations A and B is 2,800 m., which on the plotting board is as indicated on figure 1 (the scale on the original being 1 cm. to 200 m.). The method of finding horizontal distances, altitude, wind directions, and velocities is as follows:

Set the celluloid protractor with 0° on station B. Set movable arm at 310°. From B follow line on azimuth 190°. Where the 190° line meets the protractor arm, place point 1. The distance of point 1 from A is shown by the scale on the arm to be 550 m. Set movable arm at 20° on the vertical quadrant CD (as now placed). Follow horizontal line from 550 on scale AC to arm. The altitude, which is measured by the distance on this horizontal line, is shown by the scale to be 200 m. The same method of finding horizontal distances and altitudes applies to all other minutes. To find wind direction at the end of the first minute move the celluloid protractor so that A and point 2 are on the same vertical line, and read wind direction at C from the celluloid protractor. For the end of the second minute set points 1 and 3 on the same vertical line, and read direction at C. To find the velocity at the end of the first minute measure from A to point 2. The distance A to 2 is 63 mm. on the full-sized plotting board; 63 mm. is equivalent to 1,260 m., the distance traveled in 120 sec., or at a rate of 10.5 m./s. The same result would have been obtained by dividing 63 by 6. For the velocity at the end of the second minute measure from 1 to 3, and divide by 6. The same method applies to all minutes following. Obviously, if the direction is changing from minute to minute, the velocities so computed will be somewhat too small. In practice, however, the results are sufficiently accurate, considering other sources of error.

SOME OBSERVED IRREGULAR VERTICAL MOVEMENTS OF PILOT BALLOONS.

By Lieut. I. R. TANNEHILL, Signal Corps, Meteorological Service.

[Dated: Fort Hancock, N. J., May 30, 1919.]

In a quiet atmosphere the rate of ascent of a pilot balloon does not differ materially from that computed from formula. For ordinary purposes it is a constant rate.[1] When there is active convection, however, there may be irregularities in the rate of ascent and the average vertical movement of the balloon may differ widely from that assumed. These variations from the computed rate are due, undoubtedly, to vertical movements of the air and may be taken as a measure of upward and downward components of wind movements.†

When there are ascending air columns, there must be rotary movements in many cases,* but these whirls do not appear in the horizontal projection of the balloon's path, for this path shows only the movement of the balloon with reference to a point on the earth's surface and the rotary motion would be such with reference only to the air in the stratum in which the balloon drifts. If there were a whirl under a cloud, the balloon would move in a spiral with reference to the cloud but not with reference to a point on the earth's surface, unless the cloud be stationary. A flight giving a wavy projection was replotted with reference to the air, by subtracting the average wind movement (in both magnitude and direction) from each balloon minute's movement. The result was a circular path, as expected. It seems that when the balloon is rising at rates greater than that computed such unusual motion is evidenced by a wavy projection.

The whirls which appear in the horizontal projections of the paths of pilot balloons seem to be whirls in another sense.[2] In these cases there seems to be a straight wind at any level, yet the balloon moves in a spiral course because it rises through strata with various wind movements. It does not seem likely from a study of such cases that the balloon would move in a whirl if it did not rise.

For these reasons—(1) that the balloon rises in a quiet atmosphere at a rate which is nearly constant and (2) that although convectional movements of the air may be typically rotary, the balloon does not necessarily (and probably rarely does) move in a spiral with reference to a point on the earth's surface—it seems safe to use the irregularities in the rate of ascent of pilot balloons as an indication of vertical air movements.

It is the object of this paper, then, to discuss briefly the irregularities that are observed in the ascensional rate of pilot balloons, particularly beneath clouds, as indicating vertical movements of the air.

As to unusual differences, the following is an illustration: On June 13, 1918, at 1:20 p. m., at Fort Monroe, Va., a pilot balloon with an ascensional rate of 193 meters per minute from formula[3] was observed with two theodolites to rise at an average rate of 396 meters per minute for five minutes before passing into a cumulus cloud. This occurred with a fresh northwest wind, temperature 23° C., and pressure 756 mm. In Table 1, the rate of ascent of this balloon is compared with others launched on June 12 and 13, 1918, at Fort Monroe.

TABLE 1.—*Heights of pilot balloons observed with two theodolites at Fort Monroe, Va., June 12 and 13, 1918.*

Date.	Time.	1	2	3	4	5	6	7	8	9	a	b
June 12, 1918	1:05 p. m.	200	440	700	920	1,195	1,430	1,680	.....	.....	187	240
June 13, 1918	8:25 a. m.	150	400	760	930	1,170	1,270	1,510	.....	.....	172	216
June 13, 1918	9:38 a. m.	....	520	800	1,030	1,220	1,520	1,750	1,960	2,150	196	239
June 13, 1918	1:20 p. m.	420	850	1,250	1,670	1,980	.....	.....	.....	.....	193	396
June 13, 1918	2:30 p. m.	270	350	520	600	725	855	1,105	1,375	1,650	....	....

In columns headed 1, 2, 3, etc., is shown the height of the balloon at the end of each minute. Column headed "a", gives the computed rate from formula and column headed "b" gives the actual average rate taken from the height of the balloon at time of last reading with both theodolites. Heights are in meters and rates of ascent in meters per minute.

It is apparent from an inspection of this table that there were local strong vertical movements during the afternoon of the 12th and the day of the 13th. Therefore, this phenomenal rate of ascent of one pilot balloon (396 meters per minute) was evidently due to atmospheric conditions. At 2:30 p. m., the same day, one hour and ten minutes later, a balloon was launched which rose very irregularly, as shown in the table. During the second and

[1] See pp. 211–212, above.

*Dust whirls at times become cloud-capped; also the whole base of a large cumulus has been seen to rotate slowly.—C. F. B.

†This explanation may not be applicable to those irregularities observed when local vertical currents may not be present. Thus, R. Wenger (Ann. d. Hydr. u. Mar. Met., 1917, vol. 45, pp. 121-137), after considering the air resistance of spheres in air of varying degrees of turbulence and the observed variations in the rates of balloon ascents, concludes that "The changes in the conditions of turbulence of the atmosphere explain qualitatively and quantitatively all variations which are observed in the ascensional rates of balloons," and that "It is not possible, from the variations of ascensional rate to come to any conclusions as to the vertical movements in the atmosphere."—C. F. B.

[2] See MONTHLY WEATHER REVIEW, Dec., 1918, 46: p. 553.

[3] See pp. 211 and 218, above.